THE IMPACT OF SOCIAL AND FORMAL TRAILS ON TREES IN FOREST HABITATS

by

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A Thesis
Submitted in partial fulfillment
Of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
June 2024

This Thesis for the Master of Environmental Studies Degree

by

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has been approved for

The Evergreen State College

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________________6/7/2024_______________

Date

ABSTRACT

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Katherine Hall

This study observes the potential impacts social and formal trails have on the surrounding trees in the Evergreen State College Forest. The literature review found that trails can impact surrounding trees due to, among other factors, the increase of forest canopy light and the sensitivity of trees to human trampling. However, most studies were done on formal trails rather than social trails even though the few studies on social trails suggest that they might have far more impact than formal trails. This thesis focused on this literature gap, specifically how, social and formal trails impact the trees in the forest of Evergreen Street College. The purpose of this thesis is to better understand trail impacts so we can better manage and restore our evergreen forest habitats.

Methods involved collecting data every 20 meters on seven separate social trails and one formal trail built in the 1970s and maintained since then. At each station the width of the trail was collected. Two closest trees on either side of the trail was identified and DBH, species, and distance from trail were recorded. Correlation calculations were conducted to determine if there is a pattern between trail width and either tree distance or DBH. This analysis showed that more developed trails did indeed have a relationship between trail width and both tree distance and DBH while less developed trails lacked statistically significant results. More developed trails are far wider and have more people trampling the surrounding environment than the less developed trails, making the damage far more extensive. Many other factors beyond trail width might impact surrounding trees, which opens opportunities for new studies to better understand the impacts of social trail

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Acknowledgements

I want to thank my husband for being my rock. I’m so proud of him finishing his bachelor’s this year. I want to thank my parents for providing immense support to both my husband and I though this difficult journey. Thank you, Dylan Fischer, for providing essential information on the school’s trail system and providing access to your valuable research. Thank you, Frederica Bowcutt, for being my advisor. I learned a lot from you and appreciate the direction you gave me on my thesis. Lastly, thank you Kevin Francis for being my advisor for the last half of my thesis. It was scary changing direction, and you were there in support through the process. Through your amazing advice I was able to complete my thesis.

Chapter 1-Introduction

My current career path has been immersed in trail maintenance. I worked for Washington Conservation Corps for a year and currently work for Washington State Parks. During my time working for the Washington Conservation Corps, I learned so much about trail maintenance. I've pruned back branches and used a weed-eater to cut back brush so people can enjoy an open trail free of obstacles. I have climbed Mount Adams to conduct drainage work, rerouting water that was running through the trail, destroying the tread. I have tackled blackberry, holly, and Scotch broom surrounding the trail edge that was choking out the native species. I have built bridges, boardwalks, and fences to ensure the safety of the trail. I have even built a brand-new trail at Panther Creek Falls trail in Carson, Washington, which takes you to the gorgeous waterfall. However, this trail was steep; and tended to get wet by the falls. A person unfortunately died due to the failure of making the trail safe. My crew and I were tasked to create a brand-new trail that had a softer and safer slope down to the falls point (Figure 1). Throughout my time at Washington Conservation Corps, I learned the back breaking work it takes to maintain a trail.

My career in Washington State Parks still involved trail maintenance, but as a manager I learned a different side of trail management. I learned the big questions that are hard to answer. What areas of the parks should we allow people and which areas of the park should we fence off for restoration? How can we make recreation enjoyable without destroying the precious wildlife? How much money can we spend on restoration vs. recreation? What partners should be involved? Trail maintenance is more than lopping a few branches back. It is a complex beast that involves constant back breaking work, restoration and recreation goals, and complicated finance decisions. The mission behind a trail seems simple: To provide recreation while mitigating the human disturbance to the environment. But to achieve this mission is not as simple as it sounds.

Figure 1.

Panther Creek Falls trail construction

Note. Panther Creek Falls trail project. Left: mid construction of the trail. Right: A section of the completed trail.

There are a multitude of trails in the United States alone. Most trails reside in parks. In the United States there are 425 national parks (Lower and Watson, 2023) and 2,474 official state parks (American's State Park staff, 2023). The Trust for Public Land released their annual city parks data in 2011 which informs how many parks are in a city. Their data from just the 100 largest cities revealed 22,493 public parks (Trust for Public Land, 2011). USGS is currently working on digitally mapping trail systems in the United States (Figure 2). This project has mapped 277,254 miles of trails to date (National Digital Trails, 2022).

Figure 2

USGS trail project

Note Trails currently mapped in USGS project (National Digital Trails, 2022).

What is a trail? The answer is far more complex than some dirt path in the woods. Formal trails are planned and constructed by an organization. Informal or social trails are constructed by the visitors, branching off the constructed formal trails. Both types can do great harm to the environment if they are not made sustainably. A sustainable trail minimizes the environmental damage the trail causes. It may not be obvious, but a trail not built or maintained to minimize damage can greatly harm the surrounding vegetation and soil. A trail on Mount Kosciuszko had been closed to humans for 15 years due to recreational damage. After 15 years 26% of the ground near the trail was still barren of vegetation and the area was covered in invasive species (Scherrer and Pickering, 2006). Trails need to be built to handle the people using the trails, even more important today with the increase of people using the trails after COVID.

The urge to reconnect with nature was amplified during the COVID-19 pandemic. International tourism throughout the pandemic dropped due to the risk of traveling. As international travel fell, domestic travel rose, with a noticeable trend that people were favoring ecotourism (Obradović & Tešin, 2022). Before the pandemic, people chose nature-based tourism for vacation 73.9% of the time. During the pandemic, people choosing nature-based tourism for vacation rose to 95.8% (Obradović & Tešin, 2022). It is clear outdoor recreation became a method of escape during and after the pandemic. However, with more people recreating on unsustainable trails the likely damage to the environment has increased.

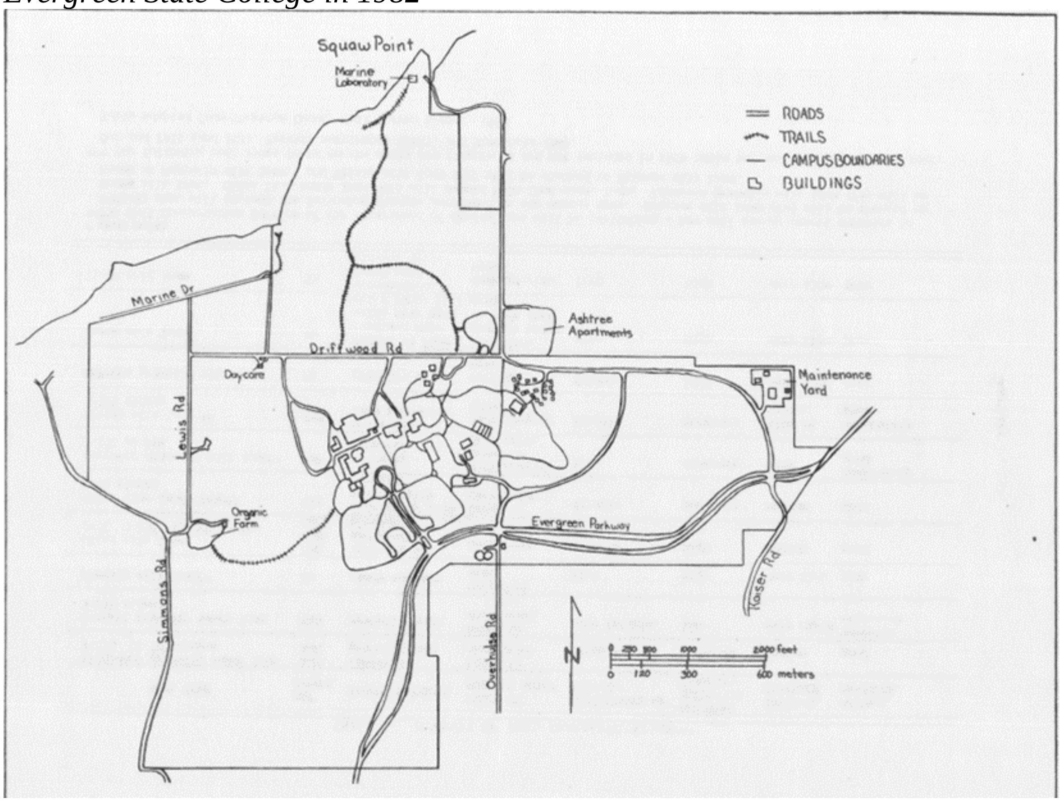
Trail management may not seem as important as saving endangered species or preventing climate change. However, it is an essential piece of the puzzle to live more sustainably and minimize our human impact. An improper trail will offset any restoration attempts. Trails are often inherited by old road systems that were not built for recreational use (Marion and Leung, 2004). How can we restore a habitat when there is a trail in said habitat off setting all the work done with its damaging properties? The solution is not to remove the trail or restrict access because protective areas rely on money inflows from recreation activities to stay afloat (Marion, 2023). The solution is to find a balance between restoration and recreation.

This is a study on comparing social trails and formal trails and their impact to the trees in secondary forest habitats. Specifically, the research question for this thesis is: How do social and formal trails impact the trees in the forest of the Evergreen State College? Studies have mainly focused on formal trails. Formal trails and informal trails can impact the environment differently. One is not better than the other. Understanding the pros and cons to each type will help trail managers decide which trail will be most appropriate for an area in terms of minimizing human disturbance.

The Evergreen State College was founded in 1967 in Olympia, Washington, in the Puget Sound lowlands. Before the college was built, the land was home to residences and small farms. Timber harvesting was common, and this land was logged in 1930's and 1940's (Speaks, 1982). The college sits on 396 hectares, with part of this land was dedicated to the college buildings and the vast majority filled with secondary forests dominated by conifers and hardwoods. When the college opened there were two trails provided (Figure 3). Today there are many trails meandering through this forest. The trails are mostly socially made and are hardly maintained by the school. This study will examine whether these social trails impact the surrounding forest any more or less then the maintained formal trail.

Figure 3

Evergreen State College in 1982



Note. Map of the trails at the Evergreen State College during the 1982 soil and vegetation analysis. (Speaks, 1982)

Methods involved collecting data from eight separate trails. One trail is the main trail that takes visitors down to the college beach. Seven social trails branching off the main trail were also selected for study. However, as discussed more fully in the discussion, some of these social trails are now so well-established that they resemble formal trails. For each trail, I collected the following data ever 20 meters: trail width, distance to closet tree to the trail on either side of the trail edge, DBH of closest tree, and species of closest tree.

The next chapter explores recent literature on recreation ecology and the impacts that hiking, horseback riding, and biking have on the vegetation surrounding the trail path as well as possible management strategies to mitigate damages. The following chapters describe the methods of this study and presents the direct observations and correlation results of data collection. The final two chapters. discuss the results and their implications, along with future directions for research on social trail impacts.

Chapter 2-Literature Review

1 Introduction

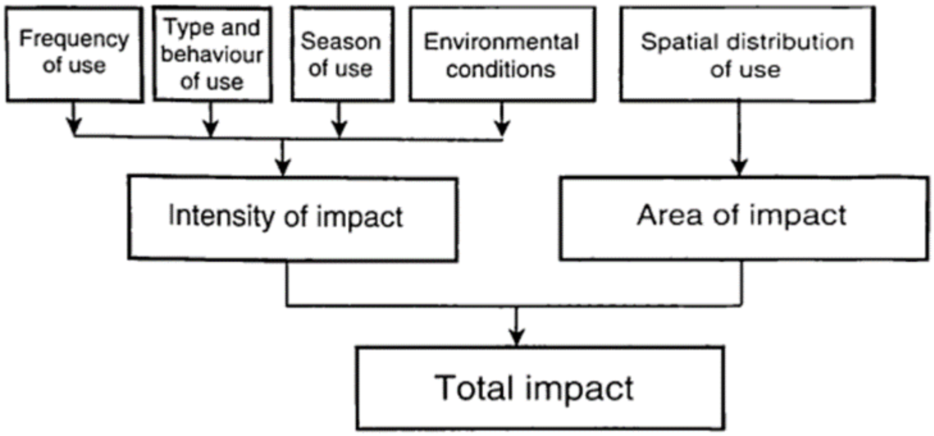
The goal of this literature review is to understand how recreation and trail maintenance damages the surrounding vegetation. This review will first explain the impacts of recreation and the trails themselves. The first section explores how the three most popular recreation activities—- hiking, biking, and horseback riding—- damage the surrounding vegetation. The second section explores the ability of a plant to handle disturbance through morphological characteristics. Certain plants have better adaptation to handle human disturbance which leads to changes in the vegetation community surrounding the trail. The third section will focus on the importance of maintenance. The fourth section explains the difference between formal and social trails and how each type of trail can cause different environmental impacts. The conclusion wraps up with a prediction on what this research study might find based on the knowledge presented in the literature review.

2 Recreational Impacts on Vegetation

The recreational user is a damaging component to the environment surrounding the trail. The total impact of recreational activities depends on several different factors. (Cole, 2004). Conditions that influence the intensity of impact are frequency, recreational activity, season, and environmental conditions (Figure 4). Area of impact is determined by spatial distribution of the activity. Together, area of impact and intensity of impact determine the total impact (Cole, 2004). The most popular recreational activities are hiking, horseback riding, and mountain biking, which will be discussed in this review while using Figure 4 as a guideline to understand the total impact specifically in forest habitats.

Figure 4

Components of recreation impacts



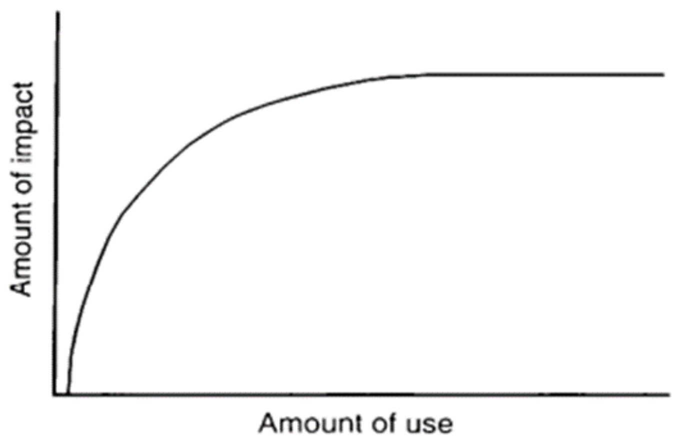
Note Displays the components of recreation impacts and how this is used to calculate total impact. (Cole,2004)

2.1 Hiking

Hiking is the most common recreation activity and trampling the most common hiking disturbance on trails. The intensity and frequency of trampling during trail use is an important factor in quantifying vegetation damage. Light levels of trampling reduce vegetation cover, plant height and seed development. Moderate levels of trampling harm the health and biomass of the plant. A shift in the vegetation community also occurs with stress-sensitive plants along the trail starting to die off, and more stress- resistant plants starting to grow more along the pathway. Lastly, high levels of trampling remove plants almost completely, with just the most stress resistant plants surviving on the trail edges (Marion et al., 2016). In deciduous forests vegetation loss is influenced by these trail intensity patterns. Vegetation has been found to decrease from 16-31% impacted by 0 visitors passes to 86-100% impacted by 25-500 visitor passes. (Thurston and Reader 2001). Cole (2004) provided a visual representation of the relationship between user intensity and impact (Figure 5). As shown in the figure, trails used infrequently create a high impact spike. As the trail intensity increases the line forms a curve displaying a high level of impact as the trail use increases (Cole, 2004). However, this damage has been found to impact vegetation only extending 30cm out horizontally from the center of the trail path (Thurston and Reader, 2001). Therefore, while trampling is highly damaging vegetation, hikers only impact vegetation along and near the trail edges.

Figure 5

Impact of trail usage



Note. Displays the amount of impact vs. amount of use causing environmental damage from the trail. (Cole, 2004)

Hikers indirectly impact the vegetation by being vectors for invasive seeds. Human clothes and shoes collect and spread seeds along walking paths. The distance invasive seeds travel on humans depends on the type of clothing as well as seed characteristics. Seeds with hooks or hairs have better latching capabilities and clothing with folds holds seeds for longer distances. Plants with higher seed counts have an increased chance of sticking to clothing. (Ansong & Pickering, 2014). Ansong and Pickering (2014) found this to be true when reviewing 21 studies on this topic and found that 87% of the 449 plant species that were collected off clothing, were invasive weed species. Humans can be vectors for invasive seeds, but it depends on where the person is walking. There is more of a chance of collecting invasives on shoes or clothing if walking on a road surrounded by invasive species (Ansong and Pickering, 2014). Dikens (2005) studied trails in Boundary Water Canoe Area Wilderness in Minnesota and found trails act as corridors for invasives. Invasive plants were located along the trail but no more than one meter from the trail path. Pathways provide bare soil for invasive plant species to establish, and humans serve as vectors transporting these seeds from trail to trail.

Hikers are not only trampling the vegetation but are also trampling the soil. Unlike plants, soils are not impacted immediately. The impact of trampling to soils is more of a linear graph with noticeable bare ground exposure starting after about 250 visitor passes. (Thuston & Reader, 2001). Low levels of trampling flatten the trail and the dead leaf litter. Moderate levels of trampling remove organic litter leaving the soil bare, susceptible to wind and water which removes the organic soil layer (Marion et al., 2016). Reduction in organic litter impacts all forms of wildlife (Cole, 2004). As hiker use continues the soil continues to be compacted in areas where foot travel is most common, which ultimately results in altered waterflow near the trail (Marion et al., 2016). Trampling reduces soil macropores which reduces the amount of water soil can hold (Cole, 2004). On flat trails, the terrain flattens further, creating low points on the trails. These low points become mucky during the rainy seasons. Sloped trails channel water, creating erosion on the trail line. Erosion leads to root exposure, harming the surrounding trees. Hikers tend to steer clear of the mud and eroding soil by going around, leading to trail widening. Trail widening increases trail damage to the surrounding vegetation. Vegetation damage is interlinked with soil damage because deteriorated soil impedes plant seed germination (Marion et al., 2016).

This turns into a feedback loop where less vegetation due to soil compactions leads to an increase of soil erosion as there are few plants to hold the soil.

2.2 Pack animals

Pack animals can cause even more damage to recreational trails than hikers. Their impact can rapidly alter plant communities through massive soil disturbance. Trampling impact is dependent on the animal, human behavior, and environmental conditions. The animal's weight and hoof size influence the pressure and shearing capabilities on the soil. Horses and mules are the most popular pack animals, but llamas have been increasing in popularity (McClaran, 1993). Horses exert 2000-4000 g/cm2 of ground pressure which deepens trails and exerts significant trampling of vegetation near trails (Price, 1985). In comparison, hikers only exert 640-1080 g/cm2 of ground pressure (Price, 1985). Humans often restrict pack animals to small areas when traveling on trails, amplifying the soil impacts along the pathway. Soil damage increases when habitats are wet because it increases soil shearing. Soil shearing is the process of cutting through the soil (McClearn, 1993). Overall trampling from pack animals compacts and shears the soil. Soil shearing increases erosion as it dislodges soil particles. Soil compaction reduces soil water infiltration, reducing water availability to vegetation. Similar to hiker damage, trampling from pack animals is also asymptotic (McClaran, 1993).

Grazing is another factor to consider for pack animal impacts to a trail. Pack animals graze along trails which defoliate plants, and negatively impacts vegetation. Grazing removes leaf tissue which impacts future plant growth and seed production. Grazing impact depends on the season, how often the area is grazed, and the number of animals grazing (McClaran, 1993). Grazing is further amplified if animals are confined in small spaces (McClaran, 1993). Barros and Marina Pickering (2017) analyzed 91 plots in the steppe vegetation areas in Aconcagua

Provincial Park Country. They found 80% of the plots were disturbed by human activities (Barros & Marina Pickering, 2017). This study is an analysis on the damages from grazing pack animals. Out of the plots disturbed by humans, 43% of these plots were impacted by horses which is a fair amount of damage.

Horse dung is another major problem along trails. One horse defecating on the trail could introduce up to 1g of phosphorous and 2.5g of nitrogen to the soil (Pickering et al. 2010). This increase in nutrients can alter the vegetation community to plant species adapted to increased nutrients (Pickering et al. 2010). Horses are also seed transporters, spreading invasives that survived digestion and are incorporated into feces along the trail (Pickering et al. 2010). Horses either graze in weedy pastures or are fed a feed mixture with invasive seeds and it takes an average of 3-4 days for the seeds to be defecated. (Wells & Lauenroth, 2007). Wells and Lauenroth (2007) examined twelve samples of dung along the Lower Piney River trail in Colorado. They found 10 invasive seeds and 10 native seeds in their samples, yet 85% of the total number of seeds were from invasive plants (Wells and Lauenroth, 2007). Campbell and Gibson (2001) also did a study comparing invasives on the trail and seeds in horse dung. Out of seven invasive species they found in their dung samples only one invasive was found in both horse dung and along the trail. The spread of invasives through horse dung is a small threat but has potential to be a larger one so it should be monitored (Campbell and Gibson, 2001). These studies reveal horses do spread invasive plant seeds in their dung, but the environmental conditions need to be right for the seed to germinate and result in a thriving plant. However, horse-borne seeds may still be a threat because invasive seeds are able to survive in a soil bank for a significant amount of time and germinate when the environmental conditions are right.

2.3 Biking

Compared to the research on hiking and horseback riding, there is not as much research on biking impacts on trails. However, the studies that have been done have shown biking can be an environmental concern. There are many styles of biking and the trails used generally are multiuse trails not designed appropriately for biking. (Pickering et al., 2010).

Environmental conditions and human behavior are the main factors in biker impact. Soil type, slope, and the wetness of a trail can all influence how much damage a bike can cause. Bikers have a greater impact on trails with fine, sandy soils because these trails are more susceptible to trail widening. If the soil is wet and muddy, bikes can damage trail conditions even more. Slope steepness also influences the damage caused. (White et al., 2006). The creation of informal trails is one major environmental impact bikers cause. (Pickering et al., 2010). While bikes do exert damage, it has been found this damage is not greater than the damage hikers cause (Pickering et al., 2010). Thurston and Reader (2001) found hikers and bikers cause similar damage and user frequency is more important than the activity. Even so, the damage caused by biking can open opportunities for invasive species by improving environmental conditions that aid in invasive plant colonization.

There are even fewer studies on bikes dispersing invasive plant species but from the research that has been done, bikers could be an important dispersal mechanism. Pickering (2022) found seven times more invasive seeds latched onto the bike and rider when the trail was wet rather than dry. More seeds were found on the rider and the bike when the rider went off trail (Pickering, 2022). On average, there are 8.6 million people who bike in the USA (Pickering, 2022). Due to the popularity of this recreational activity, it is clear that additional research is needed to better understand the roles bikers have in spreading invasive seeds.

3. How plant species in forest habitats handle human disturbance.

The Evergreen State College is surrounded by secondary coniferous and deciduous forest. Red alder and bigleaf maples create an open woodland community in moist sites, sharing water and light and many understory plants. Douglas-fir communities dominate the light, creating a sparse understory. Western red cedar and western hemlock communities share the space with salmonberry and skunk-cabbage. Salmonberry, skunk-cabbage, and willow dominate the bogs where few large trees are found (Lohmann, 2006).

As discussed, trampling is highly impactful to the vegetation. How vegetation defends itself against trampling depends on the native plant's morphological characteristics, the surrounding environmental conditions, and trampling intensity (Kuss, 1986). Certain plant species can handle disturbance and recover, while other plant species are highly sensitive to disturbance.

Morphological characteristics aid plants in handling disturbance. Plant species with characteristics such as flexible stems, and, basal leaves, can produce many offspring, and ground surface renneting buds have a better chance surviving trampling disturbance. (Kuss, 1986). The Raunkiaer's system is the most popular classification method for plant life forms. Five life forms are recognized through this system which classifies plants by the location of their perennating bud. Most evergreen plant species are classified as phanerophytes, plants that have renneting buds shooting up in the air (Niklas, 2008). Woody plant species also have tall growth forms and broad leaves. Woody plants are therefore susceptible to trampling due to their morphological characteristics. Trampling breaks off woody stems removing growing tips and flowers (Marion, 2016). Deciduous forests are sensitive to disturbance as they are covered in stress intolerant understory forbs (Thurston & Reader, 2001). There are other factors that can aid or hinder a plant's ability to handle disturbance, but woody plant species are disadvantaged due to their morphological characteristics.

Environmental conditions can add stress to a plant, reducing the plant's chance of survival. Environmental stresses that are common in forested habitats are lack of light and water scarcity (Niinemets, 2010). Water scarcity can impact both small and large trees. A smaller tree has root systems which can only reach surface water supplies. This surface water supply will dry up during drought periods. Larger trees have longer roots, that can tap into deeper water pools. While longer roots can aid trees, with the increasing temperatures due to climate change this is becoming less of an advantage. Larger trees receive more light, increasing their levels of evaporation along their crowns. Days with high temperatures increase the water demand for this tree because of the higher evaporation costs (Niinemets, 2010). Light scarcity is an increasing stressor for understory plants in closed forests. In closed forests less light reaches the understory, limiting the growth of understory plants (Niinemets, 2010). The Puget Sound area where The Evergreen State College is located has wet winters and dry summers (Lohmann, 2006). Water is readily available during the winter, but summer often experiences drought events. The stress of drought during the times when trails are most popular could cause major impacts to the local vegetation.

The amount of trampling a plant can handle varies between the disturbance intensity and the vegetation type. Each species has a threshold level, with damage beyond the threshold causing many issues to the plant (Cole, 1995a). Thurston and Reader (2001) observed hiking and biking impacts to vegetation in deciduous forests. Vegetation loss was significantly impacted by the number of passes from visitors, from 16-31% for 0 passes to 86-100% impacted by 25-500 visitor passes. Every plant in the center zone along the trail was damaged after just 25 passes

(Thurston & Reader 2001). Woody plant species, therefore, have a small threshold level for disturbance.

Trail analysis studies have found that due to the high trampling impact on woody plant species there is a shift in the vegetation communities surrounding the trail. Atik and colleagues (2009) discovered this when researching a park dominated by sclerophyllous, evergreens, and shrub species. Atik and colleagues (2009) found an increase in species richness due to the active trail maintenance on the thinning of the tree canopy near the trails (Atik et al., 2009). Bright (1986) studied the deciduous forest in Texas and found leaf litter and canopy stratification was less on the trail plots than on the control plots. This led to the pattern of increaser species growing along the trailside because leaves create more shade which these increaser species are intolerant of (Bright, 1986). Hall and Kuss (1989) looked further east in the deciduous forest in Shenandoah National Park in Virginia and found similar results. Hall and Kuss (1989) found 80% more flora plant species along the trailside. Depending on the habitat, plant species may benefit from trampling as it reduces competition, providing space for other species to grow that have less competition capacity (Cole, 2004). However, this opens the environment to invasive plant species and with their more competitive traits native species might not have a chance to grow in the newly open soil. Bright (1986) found seasonality to be an important factor. There were more invasives in autumn as they could handle the increase of visitors during the summer along with the summer drought. Invasives are opportunistic and can handle the stress of trampling (Bright,1986). The trail edges are therefore perfect for these uninvited plants.

<u>4. Trail Building and Maintenance</u>

Recent research has found the worst damage from recreational trails is not the people using it but the construction of the trail itself. There are a multitude of components to consider when building a trail and many agencies are involved in the planning process (Marion and Leung, 2004). Trail planning is an extensive process that involves setting goals, objectives, monitoring, and evaluation (Marion and Leung, 2004). The overarching goal for all this planning is to make a trail environmentally sustainable. A sustainable trail is defined as a trail that provides for recreational purposes while also minimizing the harm to the ecosystem (Emery, 2023). This overarching goal is rarely met. Many trails were inherited from old roads or firefighting trails (Marion and Leung, 2004). These trails were not designed with sustainability in mind (Marion, 2023). While this will save everyone time and money these trails were not built for recreational purposes and therefore cannot be sustainable as a recreational trail. A step often missed in the planning process is the evaluation of the social conditions (Marion and Leung, 2004). It is vital to first ask what recreational activity this trail will be used for. As discussed previously, hikers differ from pack animals in their trail impacts. To have a sustainable trail it is vital to understand the possible impacts and how to minimize these damages. This improper planning can have massive consequences down the road as the amount of people using these unsustainable trails continues to grow.

Overall, the knowledge on how to build a sustainable trail is lacking. Management has been mainly guided through the years of experience rather than trail science (Marion, 2023). Land management rarely funds trail science and management literature is based largely on experience rather than the citations of trail studies. Few of these books speak of sustainability, but rather these books focus more on root basic knowledge of trail maintenance (Marion, 2023). When I started my career in trail maintenance through the Washington Conservation Corps I learned through the knowledge of my supervisor. I was never encouraged to look up the science behind my supervisor's teaching. I had an amazing supervisor that taught me trail sustainability practices but at the end of the day we were working for someone and completing the job was more important than sustainability goals. There is nothing wrong with trail experience but there needs to be a merger between experience and science so future trail development will have sustainability in mind and have the knowledge to do so.

There are many components that make a trail sustainable. The most common failures in trail sustainability are steep trail grades, improper trail alignment angles, and crossing water systems. Trail grade is the elevation gain or loss through the whole trail. The trail grade corresponds with the difficulty of the trail, the higher the trail grade the steeper the trail is. Steeper trail grade has been found to critically affect soil loss on the trail path (Marion, 2023). Trails need to stay around a trail grade of 12% or less to be sustainable (Marion and Leung, 2004). Many protected area trails exceed this percentage (Marion, 2023). It has been found that an average of 23cm2 of soil will be lost for every one percent increase after the trail grade reaches eleven percent (Marion, 2023). Soil erosion exposes rocks and increases muddiness which leads to braiding—- the trail breaking up into multiple smaller trails—- and trail widening (Marion and Leung, 2004). However, a trail cannot be completely flat, or it will also experience muddiness and braiding. Therefore, the most sustainable trails will have a trail grade of 3-10% (Marion, 2023). The trail alignment angle is the angle the trail holds along a slope. A proper trail alignment would allow water to flow from the slope and then right off the trail. A low alignment angle would not allow water to flow causing erosion and muddy trails (Marion and Leung, 2004). The best trail alignment angle will be 31-90 degrees. Lasty, a sustainable trail limits the amount of stream crossings to avoid erosion and stream runoff (Marion and Leung, 2004). While these are essential components to think about when creating a trail, the first step is to decide what type of trail to build.

5. Social vs. Formal Trails

The type of trail being built is a major decision that needs to be made prior to trail construction. Formal trails are trails constructed to have compacted soil and are maintained by managers. Informal trails are constructed by users, not well maintained, and do not have the soil compacted (Ballantyne et. al, 2015). There are pros and cons to each trail type. Formal trails tend to have less erosion and widening due to the efforts of hardening the trail (Ballantyne et. al, 2015). However, the construction of the formal trail involves removing vegetation along the path which puts threatened plant species in greater risk of extinction (Pickering and Norman, 2017). The machinery used to construct the trail damages trees located along the path further damaging the vegetation community (Ballantyne et. al, 2015). Social trails tend to have more soil erosion and trail widening issues due to the lack of trail hardening. Due to their poor design, muddiness is a common issue which people avoid by stepping off trail (Pickering and Norman, 2017). This behavior amplifies trail widening and braiding.

In forested ecosystems both social and formal trails impact the trees. Formal trails remove trees during construction, creating canopy gaps which lets in more light and heat into the forest (Pickering and Norman, 2017). The creation of informal trails reduces tree canopy and reduces tree density (Ballantyne et. al, 2015). Large informal and formal trails have similar impacts to tree reduction, but informal trails eventually have a greater impact as these trails continue to widen (Ballantyne et. al, 2015). This increase in light and heat has been found to benefit sapling regeneration. In a study on a spruce-dominated forest, tree samplings were found abundant near the trail edges because of the extra light and temperature (Lehvavirta et al., 2014). More trails in a forest creates more fragmentation and edges, amplifying the heat and light in the forest. However, more trails do not always lead to good things. Trampling is still a factor and while a small amount of trampling promotes regeneration, too much trampling impacts the survival of the sapling (Lehvavirta et al., 2014).

It has been argued that, social trails generally have a higher impact on the vegetation than formal trails (Cole, 2004). While formal trails seem to be the more sustainable solution, without proper maintenance or poor design these trails could have a substantial impact on the environment (Cole, 2004). Furthermore, there are more trails than managers can maintain (Marion and Leung, 2004).

6. Conclusion

Trail studies have discovered three overarching themes. The first theme is different activities produce different environmental impacts. Hikers trample the surrounding vegetation, pack animals graze down plants near the trails, and bikers create social trails that cause, habitat fragmentation. The second theme is plants handle disturbance differently depending on their morphological characteristics. Woody plants are more susceptible to trampling due to their broad leaves and perennating buds. The last theme is social trails and formal trails impact the environment differently. Formal trails tend to have fewer erosion issues, but the creation of these trails involves removing valuable vegetation. Social trails tend to have issues in trail widening, erosion, and habitat fragmentation. It has been found social trails are the most destructive due to their trail widening and spread of impact.

Trail studies are not heavily studied and there are many gaps into the research. Trail studies have only been studied in a few countries. Also, threatened ecosystems have not been prioritized. Few papers have focused on the landscape view on how trails impact reaches further than just the trail edge. Lastly, there are few studies on informal trails (Ballantyne et. al, 2015). All the research has found that trails impact the environment. This topic is therefore important for scientific research because answering how trails impact the environment will help trail managers build sustainable trails. This thesis will branch off the current work and answer a question yet to be answered: how do social and formal trails impact forested systems?

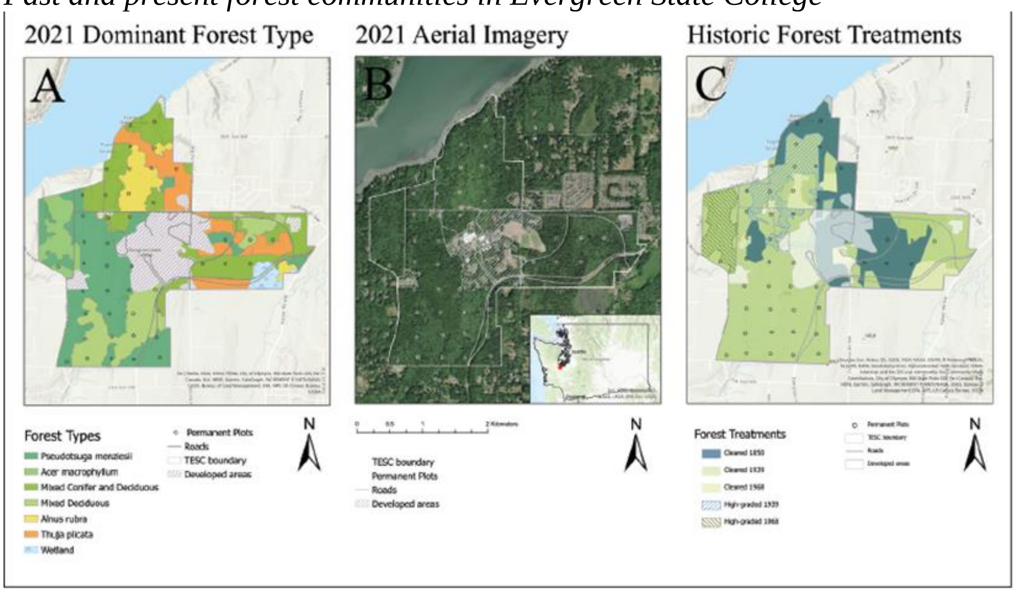
Chapter 3-Methods

1.0 Site Description and History

In 1965 the Washington Legislature formed a temporary council to research the need for higher education in Washington. The council recommended a four-year university in Thurston County. Evergreen State College became the first public college university (Kormondy, n.d). After the stop of logging activities, the land around the college regrew to secondary forests dominated with conifers and hardwoods. Due to the high disturbance of timber harvest, this secondary forest is a mosaic of different vegetation communities (Speaks, 1982). (Figure 6A).

Figure 6

Past and present forest communities in Evergreen State College



Note. The Evergreen State College Forest. A: Current forest communities. B: Aerial view of the forest. C: Historic logging of this forest. (Rex & Bartlett, 2023)

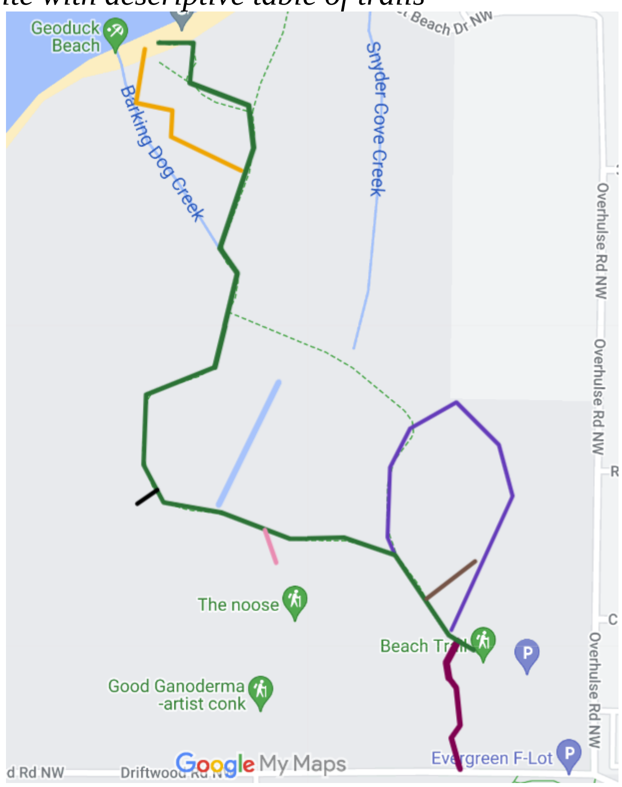
2.0 Methods

2.1 Classification of formal and social trails

For this project I analyzed the social and developed trails branching off the formal beach trail maintained by Evergreen State College. Formal trails are made and maintained by trail managers and companies and the trail is usual hardened. Informal trails are made and maintained by trail users, usually branching off the formal trail. People typically makes these trails to further explore the area or to shortcut part of the formal trail (Ballantyne et. al, 2015). For consistency, the social trails considered for this project had to connect with the maintained beach trail. Any social trails branching off the selected social trails were excluded from analysis. Below is the map of the trails selected for this project.

Figure 7

Study site with descriptive table of trails



Trail Name	*Color on the map*
Main	Green
Loop	Purple
Beach	Yellow
Creek	Pink
Road	Red
Connector	Brown
Campsite	Blue
Shortcut	Black

Note. Map of the selected trails with a table describing the trails. The trails don't have names, so names were given to distinguish the trails in this study.

2.2 Survey Techniques

This study will use correlation to determine if trail width influences tree distance and DBH. Correlation does not equal causation, but correlation calculations will provide insight to these relationships which this study predicts exist. Trail width is the main independent variable. Trail width is defined as the clearing limits where obstacles and vegetation are removed to allow someone to walk through. (Hesselbarth et, al., 2007). In practice this definition is vague and a challenge to use. An example is the picture below of one of the social trails (Figure 8). Trampling and trail widening have caused diminished vegetation along the trail and for the trail to almost merge with the hillside. These areas will involve a judgement call on where the trail ends. To mitigate this, I looked to the path ahead, for trees or stumps that define the trail and used those as guidelines to where the trail ends at my data collection point. To begin, I started on the end of the trail that is attached to the maintained trail. The first data point was 0 meters. Data points were collected after every 20 meters along the trail. Using a tape measurer the trail width was recorded by placing one end of the tape measurer on one end of the trail and stretching the tape measurer to the other end of the trail.

Figure 8

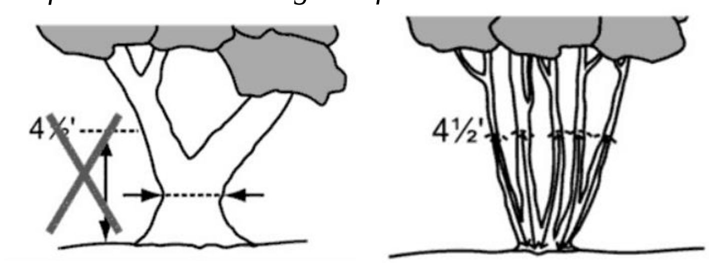
Distinguishing trail edge on the loop trail

Note. Photo of the loop trail. This area is difficult to determine where the trail edge is.

Standing at the edge of the trail where the trail width was recorded, the closet tree over 10cm DBH to the trail was selected for both the right and left side of the trail. After the tree was selected the distance of the tree to the edge of the trail was recorded. Placing the tape measurer at the edge of the trail, it was stretched to the trunk of the selected tree. DBH- (diameter at breast height)- was used to calibrate the tree diameter. This is the diameter of the tree at the average person's breast height. In research papers there is no constant number of what the average height DBH should be. I will be using the guidelines from the Portland Government which state a height of 4.5ft for DBH (Portland.Gov, n.d). For me, this means I will be measuring the diameter of the tree at shoulder height. DBH is not always easy to measure, and adjustments had to be made to record this data (Figure 9). Trees that fork into multiple trunks near the DBH marker were measured at the stem before the fork. Trees that have several trucks were calculated by measuring each truck individually at the DBH marker and then the average DBH was calculated (Portland.Gov, n.d). Lastly, the species of the tree was recorded.

Figure 9

Diagram of DBH on branching tree forks



Note. Diagram of how DBH will be calculated if there are branching forks (left) or multiple trunks (right). (Portland.Gov, n.d)

3.0 Data analysis

My data analysis was inspired by Ballantyne et al. (2015) on the impacts of formal and informal trails on forest loss and tree structure. They categorized the trails based on their width and then performed an ANOVA test to find significance between these trail width categories (2015). My study only has eight trails compared to their 17 trails, so I adjusted my study for the smaller scale. The independent variable is the trail width and the dependent variables and are tree distance and DBH. I calculated correlations to understand the relationship between trail width and tree distance as well as trail width and DBH. My prediction is that trail width influences both tree distance and DBH.

Chapter 4- Results

This chapter contains three sections analyzing different areas of the data. The first section analyzes the physical observations of each trail along with analyzing the average trail width and what trees surround the trail. The second section analyzes the correlation calculations of all the trail data pooled together. The third section analyzes correlation calculations of each individual trail to see if there are more patterns the pooled data did not foresee.

1.Observations

1.1 Main trail: Figure 7, Green

The main trail starts at parking lot E and ends at Geoduck beach. The signs along the trail distinguish the main trail from all the social trails branching off the main path. There is clear evidence this trail is maintained such as a bridge allowing one to cross the creek and a boardwalk placed in a section that goes through a muddy wetland. There are large logs dug into the ground in some sections to prevent the trail from expanding. Lastly, there is a bench placed by the beach exit. The width of the trail mainly stays within 1-2 m however there was one expansive area where the width of the trail was 4.1m and towards the beach exit the trail narrowed to .9m. Douglas fir, maple, and western red cedar surrounded the trail until reaching the beach when alder trees are dominant.

Figure 10

Photos of main trail

Note. Left: The logs that kept the trail from expanding. Middle: picture of the steps and bridge. Right: One of the expansive sections of the trail.

1.2 Loop trail: Figure 7, Purple

The loop trail branches off the formal trail shortly after the parking lot entrance and ends back on the main trail creating a horseshoe shape trail. The trail is very distinguished, it looks more like a formal trail than a social trail. This trail is clearly used frequently. The width of the trail mainly stays within 1-2m. However, there is a section of the trail that goes through an open forest and the width expands to 4m. This section is difficult to distinguish the trail and one can easily get lost in the forest. There was also a section of the trail, towards the middle, that narrowed to .8m. Douglas fir, big leaf maple, and western red cedar surround the trail path.

Figure 11

Photos of loop social trail

Note. Left: what the path typically looks like for most of the trail. Right: The wide expansive area that blends with the trail.

1.3 Beach trail: Figure 7, Yellow

This beach trail is found two thirds along the main trail. It is a steep sloped trail that ends in an open field right next to the main trail, not far from the beach exit. While the trail is easy to find at the start, there are multiple social trails branching off this social trail making it difficult to stay on the right path. Towards the end climbing over large fallen trees is required to continue along the trail. This trail is much smaller, ranging from .7m to 2.5m with most data points on width falling less than 1m wide.

Figure 12

Photos of beach social trail

Note. Left: shows the lack of trail boarders. Middle: shows the logs on the trail. Right: shows the steepness of the trail.

1.4 Creek trail: Figure 7, Pink

The creek trail branches off an expansive area on the main trail near the creek crossing. It is a very short trail, with only two data points collected, that ends at a large open space that provides a view of the creek. The width of the trail averages at .95m. Western red ceder surrounded this short trail.

Figure 13

Photos of creek social trail

Note. Left: picture of the trail. Right: Picture of the lookout at the end of the trail.

1.5 Road trail: Figure 7, Red

The road trail branches off the main trail not far from the parking lot. It parallels the parking lot and ends at the road. Part of the trail was extremely muddy, making it difficult to distinguish the trail edge. There were also two shipping crates right next to the trail path. The average width of the trail is 1.6m. Western red ceder and alder dominated this area with a few big leaf maples scattered around the area.

Figure 14

Photos of roads social trail

Note. Left: the muddy patch where the trail disappears. Middle: the shipping containers. Right: the end of the trail at the road.

1.6 Connector trail: Figure 7, Brown

The connector trail is found along the first slope of the main trail. This social trail follows back up the slope and connects to the loop social trail entrance. This trail is less distinguished than the other social trails. Plants branch onto the path and towards the end as it enters an open forest it is impossible to find the trail path. The average width was .7m with western red cedar and Douglas fir bordering the trail.

Figure 15

Photos of connector trail

Note: Left: the logs on the trail. Middle: the lack of distinctiveness of the trail. Right: the open area where the trail ends.

1.7 Campsite trail: Figure 7, Blue

The campsite trail is found near the middle of the main trail. The entrance is clear but moving forward along the path the trail narrows and is covered in ferns and fallen trees. The end of the trail is in the middle of the forest where there is a campsite hangout spot for college students. The average width is .78m with alder, maple, and western red cedar trees found around the trail.

Figure 16

Photos of campsite social trail

Note. Left: the beginning of the trail. Middle: the narrowness the trail becomes. Right: the fallen trees on the trail.

1.8 Shortcut trail: Figure 7, Black

This shortcut trail connects the main trail to another trail which is unclear whether it is a social trail or service road. The average width of the trail is .9m surrounded by alder, Douglas fir, and maple.

Figure 17

Photos of Shortcut social trail

Note. Left: beginning of the trail. Right: the middle of the trail.

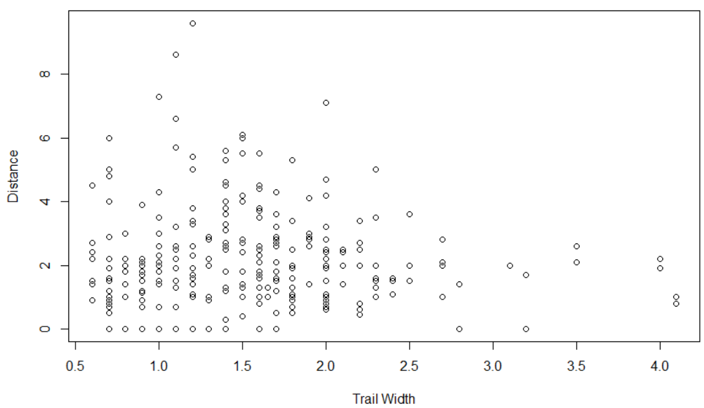
<u>2.0 Correlation of all trails combined</u>

2.1 Correlation between width and tree distance

When all trails were combined, correlation analysis of trail width and tree distance did not produce statistically significant results. ($r=-.072$, $p=.244$) (Figure 18)

Figure 18

Correlation of all trails on tree distance



Note. Correlation between trail width (X) and tree distance (Y) of all the trails pooled together.

Observations found some social trails were found to be more developed like the main trail and other social trails far less developed and used. The main, loop, and road trail are far more developed than the creek, connector, campsite, short, and beach trails. Does the condition of the trail make any difference and provide different results than all the trails pooled together? When these two categories were examined separately, correlation analysis for more developed trails produced statistically significant results with very weak negative correlation ($r = .152$, $p=.031$). Correlation analysis for less developed trails produced no statistically significant results ($r=.098$, $p=.459$).

Furthermore, the data was broken down even further to the individual tree species to understand if trail width impacts tree species differently. Douglas fir is the only tree species to show statistically significant results between trail width and tree distance. (Table 1). The correlation relationship for Douglass fir was far stronger than the pooled data and showed higher probability that trail width is indeed a factor that influences tree distance (Table 1). Interestingly, Douglas fir has a negative correlation relationship along the developed trails yet a positive relationship along the undeveloped trails.

Table 1

Values of tree species on developed and undeveloped trails

Developed	Total	Douglas fir	Maple	Alder	Western red cedar
r value	-.15	-.53	.012	.098	-.196
p-value	.031	.001	.91	.79	.104
Less Developed					
r value	.098	.808	-.0052	-.13	.104
p-value	.46	.03	.99	.69	.61

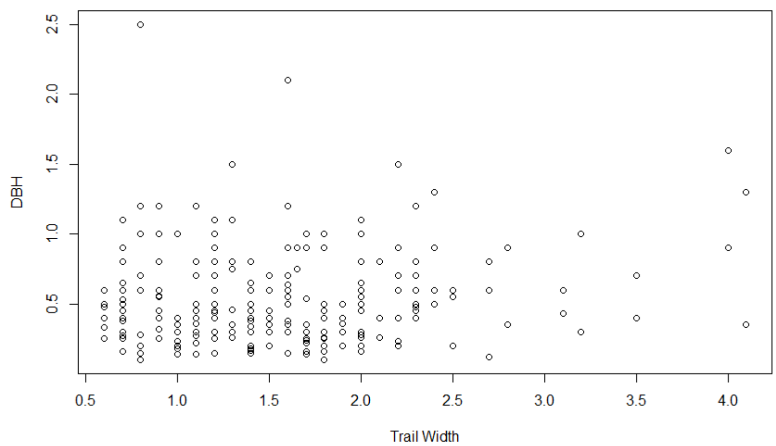
Note. p and r values of the developed and undeveloped trails and individual tree species for tree distance

2.2 Correlation between width and BDH

When all trails were combined, correlation analysis of trail width and DBH produced statistically significant results with very weak positive correlation (r=-.123, p=.047) (Figure 19).

Figure 19

Correlation of trail width vs. DBH of all trails



Note: Correlation between trail width (X) and DBH (Y) of all the trails pooled together.

Again, separating the developed and undeveloped trails finds similar results to the tree distance correlation. The developed trails showed statistical significance but weak correlation (r = .27, p = .000097) and the undeveloped trails showed no statistical significance (r = .13, p = .34). Breaking down the data even further to individual tree species leads to interesting results. Douglass fir and western red cedar showed statistical significance only in more developed trails. (Table 3). Both tree species had low correlation relationship values (Table 3).

Table 2

Values of tree species on DBH for the developed and undeveloped trails

Developed	Total	Douglas fir	Maple	Alder	Western red cedar
r value	.27	.35	.14	-.17	.33
p-value	.000097	.047	.18	.63	.005
Less developed					
r value	.13	.19	.49	-.28	.488
p-value	.34	.69	.09	.37	.809

Note. p and r values of the developed trail and individual tree species for DBH

3.0 Correlation among the individual trails

3.1 Correlation between width and tree distance

The reason for pooling all the trails together is because each individual trail did not have enough data points (Table 5). This insufficient amount of data points led to very high p-values (Table 6). The only trail that came close to significance was the main trail which had the most data points (p=.077, # of survey stations= 64). The correlation relationships were all low (Figure 20) except for the shortcut trail (r=-.97) but again, with how little data points each individual trail had, I have little confidence in these r coefficients.

Table 3

Width, trail length, and survey stations of each trail

Trail Name	Length (m)	# of survey Stations	Trail width (range in m)	Trail width (average m)
Main	1280	64	.9-4.1	.40
Loop	560	29	.8-4	1.66
Beach	240	13	.7-2.5	1.17
Creek	20	2	.7-1.2	.95
Road	140	8	1-3.1	1.6
Connector	60	4	.6-1	.73
Campsite	180	10	.6-1.1	.78
Shortcut	20	2	.7-1.1	.9
More developed trails	4,020	202	.8-4.1	1.2
Less developed trails	1,160	59	.6-2.5	.90

Note. Overall data of length, survey stations, and width of each individual trails, the more developed trails grouped and the less developed trails grouped.

Table 4

Correlation values of trail width vs. tree distance of each trail

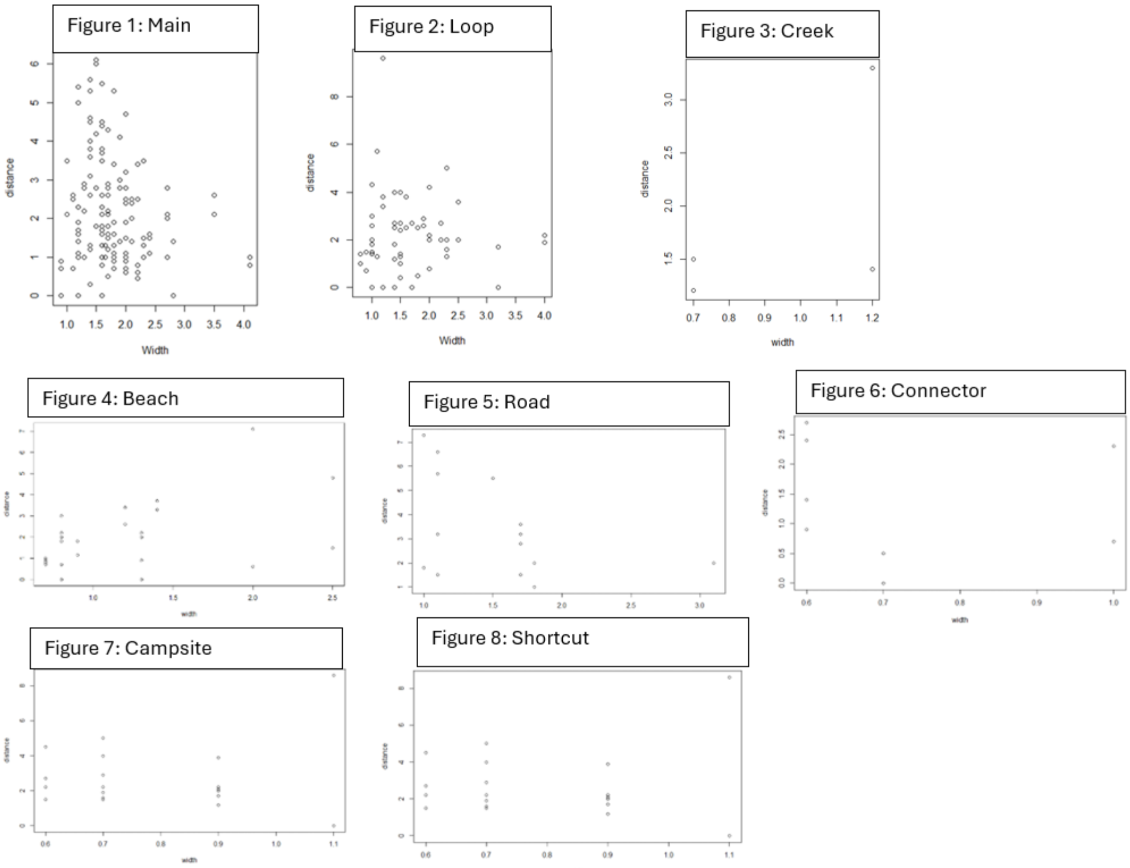
Trail	Main	Loop	Beach	Creek	Road	Connector	Campsite	Shortcut
r value	-.156	-.045	.098	.59	-.45	-.09	.12	-.97
P-value	.077	.73	.41	.096	.829	.602	.032	.008

Note. r and p-values of each trail for the correlation between width and tree distance

Correlation calculation for individual tree species for each individual trail was analyzed for possible further patterns (Table 7). There was inconsistency between individual tree species and the trail making it difficult to find patterns amongst the data and graphs (Table 7, Figure 21). This further solidifies that pooling the trails together increased the data set making it possible to find patterns within the data.

Figure 20

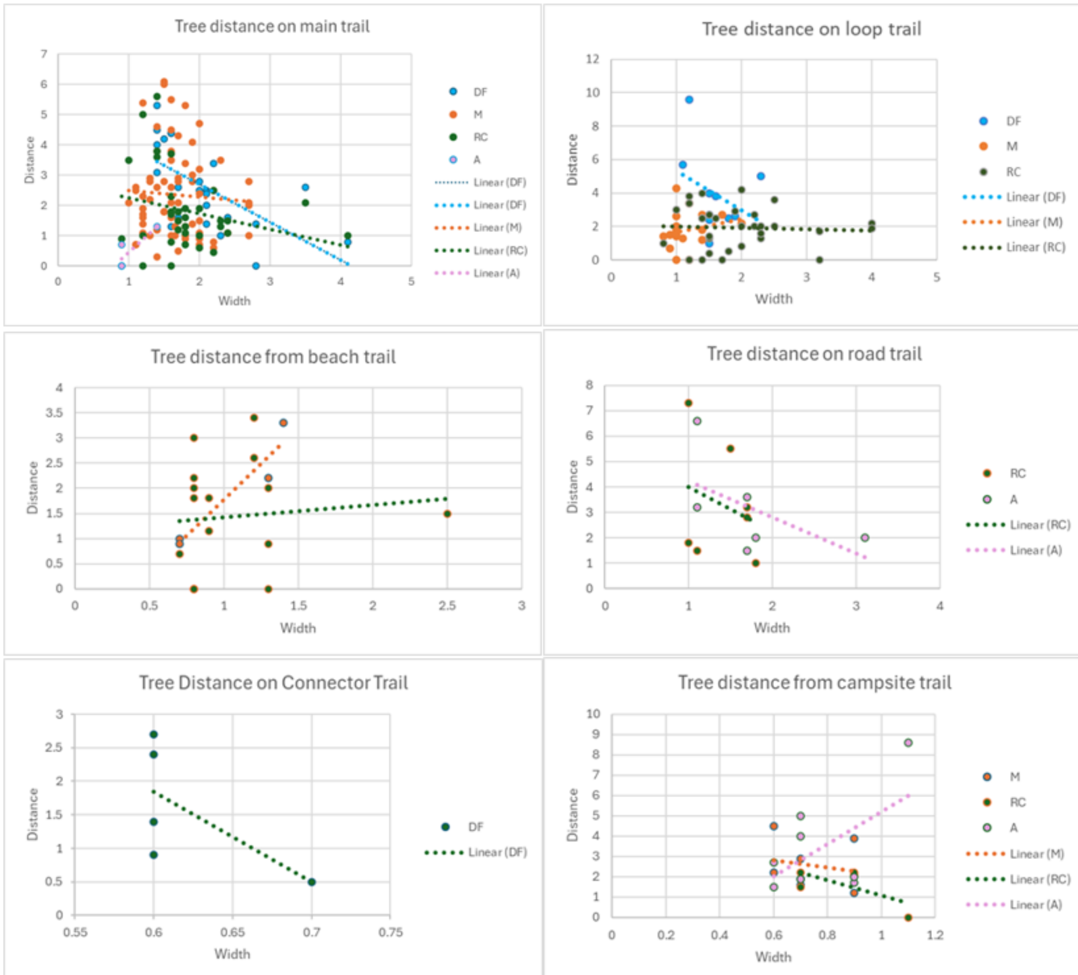
Correlation of trail width vs. tree distance of each trail



Note. graphs of each individual trail showing the correlation between trail width and tree distance.

Figure 21

Correlation of trail width vs. tree distance for each tree species



Note. Graphs of each individual tree species for each trail on the correlation between trail width and tree distance.

Table 5

Correlation values of trail width vs. tree distance on individual tree species

Trails	Douglus Fir (r, p)	Bigleaf Maple (r,p)	Alder (r,p)	Western Red Ceder (r,p)
Main	-.62, .006	-.06, .61	.85, .15	-.25, .16
Loop	-.34, .34	.22, .38		-.05, .8
Beach		.95, .045		.098, .72
Creek				.59, .41
Road			-.56, .25	-.27, .55
Connector	-.64, .25			
Campsite		-.18, .69	.57, .14	-.67, .22

Note. R and p-values of individual tree species on each trail for the correlation between width and tree distance

3.2 Correlation between width and BDH

The correlation between trail width and DBH showed a mix of statistically significant and insignificant results for individual trails (Table 8). While the connector trail (r=-.83, p=.05), campsite trail (r = .44, p = .05) and loop trail (r = .45, p = .0004) showed significantly significant results. The correlation relationship was also mixed from weaker to stronger r coefficients (Table 8, Figure 22).

Table 6

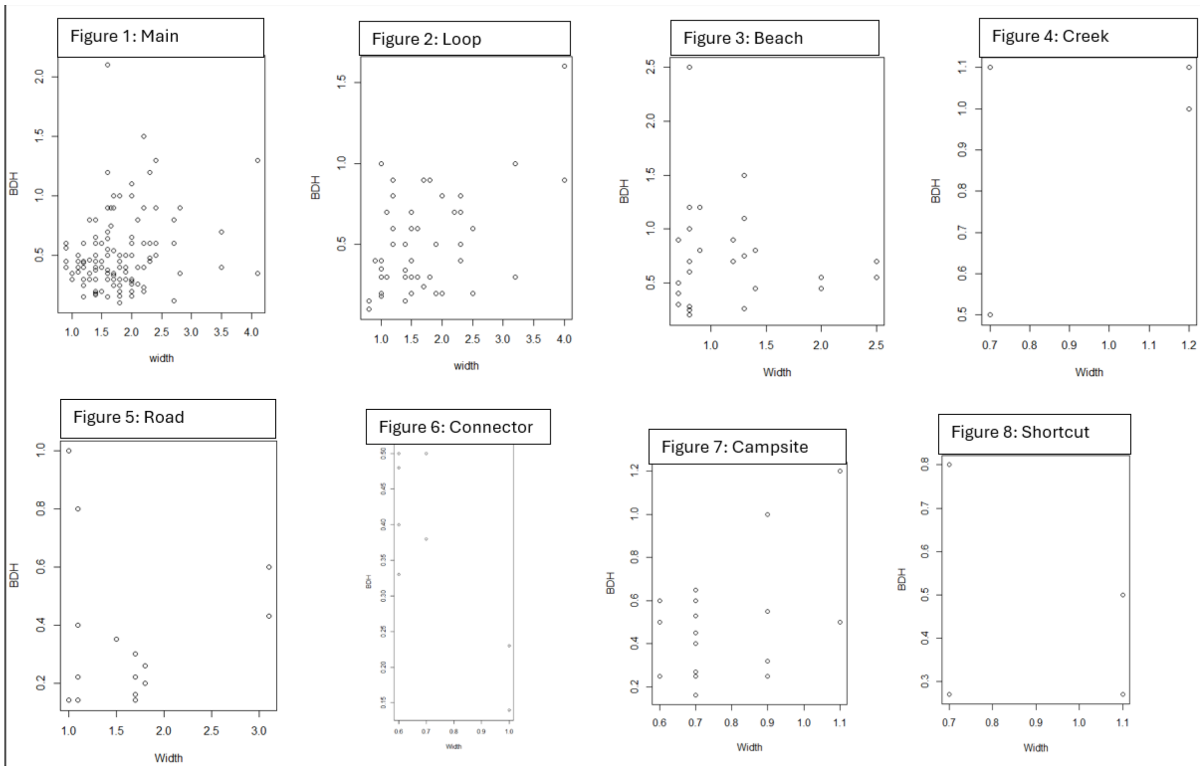
Correlation values of trail width vs. DBH

Trail	Main	Loop	Beach	Creek	Road	Connector	Campsite	Shortcut
R value	.2	.45	-.12	.50	.02	-.83	.44	-.34
P-value	.022	.00041	.4975	.952	.01	.05	.655	.601

Note. R and P-values of each trail for the correlation between width and DBH

Figure 22

Correlation of trail width vs. DBH for each trail



Note. Plots showing the correlation between width and BDH for each trail.

Conducting correlation calculations on individual tree species for each trail brought similar results as the tree distance correlations for individual trees species in each trail. There was no constant pattern making it difficult to come to any conclusions (Table 9, Figure 23).

Table 7

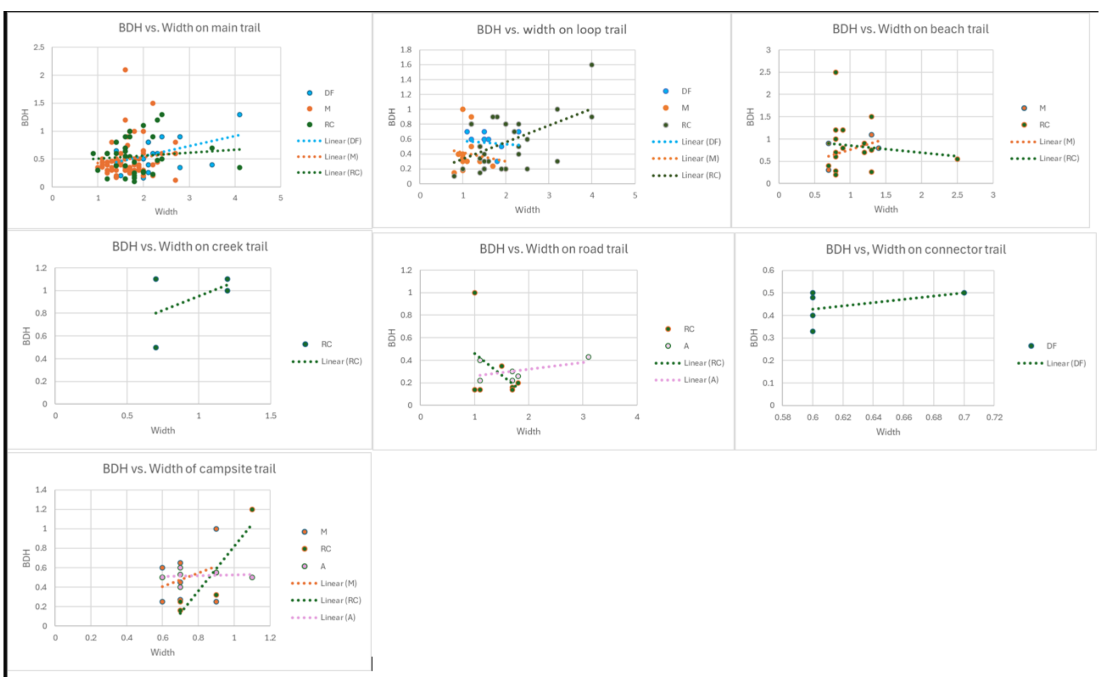
Correlation of trail width vs. DBH on individual trail tree species

Trails	Tree Species	Douglus Fir (r,p)	Bigleaf Maple (r,p)	Alder (r,p)	Western Red Ceder (r,p)
Main		.42, .05	.13, .27	.22, .78	.11, .55
Loop		-.08, .82	-.16, .53		.52, .003
Beach			.55, .45		-.13, .64
Creek					.50, .5
Road				.50, .32	-.43, .33
Connector		.43, .47			
Campsite			.32, .42	.14, .73	.92, .029

Note. R and P-values of individual tree species on each trail for the correlation between width and DBH

Figure 23

Correlation of width vs. DBH for each individual tree species on each trail



Note. Plots showing correlation between width and DBH for each individual tree species in each trail.

Chapter 5. Discussion

This thesis found there is a relationship between trail width, tree distance, and DBH. Again, correlation does not equal causation, but I predicted there was a relationship with these three factors. This method was the best way to see this relationship. My results found a weak correlation between trail width vs. tree distance and trail width vs. DBH. However, there was statistical significance that trail width of more developed trails impact tree distance and DBH. Throughout the study, the species of tree that was found closest to the trail was collected to determine if trail width impacts tree species differently. Douglas fir was most impacted by both tree distance and DBH. I have some predictions that might explain these observations.

The forest was there before the trails were created. The correlation relationship for tree distance was negative and DBH was positive. A negative correlation for tree distance means as the trail width widened the tree distance narrowed. When the social trail was first created by a trail user, it was smaller, so the trees were found further away. As the trail continued to be used, it continued to widen, narrowing the distance the trail had to the surrounding trees. A positive correlation with DBH means as the trail width got wider the DBH got larger. DBH is an indicator of the general age of a tree, the larger the DBH the older the tree is. With these correlations I predict, as these social trails widen, they encroached the space of older trees that have been there possibly before the trail was created. I predict younger trees were less likely to be found closer to the trail because they have fewer defensive mechanisms against disturbance. Also, there is less space for this new growth because the trail is taking up more space. Douglas fir was found to be the most impacted tree species in this study. Interestingly, for tree distance, this tree had a negative correlation for the more developed trails and a positive correlation for the less developed trails. In other words, Douglass fir was found further away from the less developed trails yet closer to the more developed trails. This further emphasizes my prediction that when these social trails were first created, they were smaller and therefore found further away from trees. As these trails developed into being more like formal trails the Douglas fir was found closer. This study had a small data pool so a bigger study on trail impacts to different tree species will be beneficial for more answers.

There are two possible predictions as to why developed trails impact surrounding trees more than less developed trails. One is as the trail widens the damage is spread further in the area. Trail studies have found informal trails have similar impacts to tree reduction, but eventually the informal trails have a greater impact as the trail continues to widen (Ballantyne et. al, 2015). In this study the undeveloped trails have an average width of less than a meter, expect the beach social trail which has an average width of 1.17 m. The more developed informal trails, the road and loop trail have the highest average width. The second explanation molds into the first. More people equal more impact. It is evident the less developed trails are used less often. These trails eventually blend into the woods and some of these trails are covered in ferns and falling trees. Since the more developed trails are far more used it makes sense these trails impact to the surrounding trees more than the less developed trails. The road and loop trail are used far more often and eventually these trails widened to the same width as the main maintained trail.

This study has found trail width does influence tree distance and DBH. However, the correlation relationships were weak, meaning trail width is indeed an impacting factor but there are other factors this study did not consider. This study opened the door to new possibilities in researching the impacts of social trails in forest systems.

Chapter 6. Conclusion

In the current literature there is an overall theme that social trails cause more damage to the environment than formal trails. There are several reasons for this theme. Social trails have no structure, increasing the chances of trail widening. Social trails are not constructed with a hardened tread making these trails susceptible to erosion. This further increases the issue of trail widening. Social trails also cause habitat fragmentation because many social trails break up the area into small fragments (Pickering and Norman, 2017). However, despite such widespread concerns about these environmental impacts, there are far fewer studies on the actual damage caused by social trails, especially when compared to studies on formal trails.

This study focused on the social trails in the Evergreen State Forest. After the college was built, there was a trail that meandered down to the beach and a trail that went to the organic farm. Now, there are a multitude of social trails that it is hard to distinguish what is the main maintained trail and which are the social trails. This study focused on whether there is a correlation between trail width and tree distance as well as between trail width and tree DBH. These social trails seem to appear overnight and there are so many of them a person can get lost in those woods. I predicted these social trails will impact the secondary forest habitat. The purpose of this study was to better understand the environmental impacts of social trails so the school can formulate restoration plans that look at decreasing human impact in the forest.

My results did not find statistically significant evidence that minimally used social trails impact tree growth. In contrast, my results suggest that social trails with heavy use that start to have characteristics of formal trails do have an impact on the surrounding forest. The results revealed the most important factor of impact was how well developed the trail is. It is worth doing this study again with a far larger sample size. This work suggests there is a connection and, a bigger study will provide more concrete results and will be able to further tackle the question whether trail width impacts tree species differently.

Further research should also focus on other trail factors that have been found to harm the environment. A study on the compaction of soil will determine if these social trails are impacting tree roots or inhibiting understory growth. A study on canopy light will reveal if these social trails are increasing the canopy light in the forest and how this impacts new tree growth. Lastly, a study on habitat fragmentation will reveal a landscape perspective on whether these social trails are impacting The Evergreen State College forest as a whole system. These studies will help further research on the impacts of social trails and provide insight to future maintenance.

In my experience, I have found trail managers and trail scientists are often separate. Trail managers learn trail maintenance through experience, not science. Trail science is few and far between. There needs to be a merger between these two parties. There needs to be more trail studies with the mindset to help trail managers and trail managers to learn and use the science in their work. Together, sustainable trail building can be achieved. It is time to make sustainable trails so we can maintain human impact while allowing people to enjoy the great outdoors.

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